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Neuroanatomical study

A multidetector CT angiography study of variations in the circle of Willis in a Chinese population

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ABSTRACT

The circle of Willis is a major collateral circulation that has an important role in ischemic events. The purpose of our study was to investigate the collateral circulation in a Chinese population with 64-section multidetector CT angiography (CTA). A total of 170 patients who underwent 64-section CT angiography at The First Affiliated Hospital of Chongqing Medical University were included in our study. The morphological variations in the anterior and posterior circle of Willis were assessed in each patient. A total of 160 patients were included in the final analysis, of whom 126 (79%) demonstrated a complete anterior circle of Willis, and 50 (31%) had a complete posterior circle of Willis. A complete circle of Willis was seen in 43 of 160 participants (27%). A fetal-type posterior circle of Willis was seen in 15 (9.4%) patients. This is the first report of a CTA study of collateral circulation in a Chinese population. A higher prevalence of compromised posterior collaterals was observed in this Chinese population compared to Western and Japanese populations.

1. Introduction

The cerebral collateral circulation in the circle of Willis is an important potential pathway that maintains adequate blood flow in various ischemic conditions.[1–3] In patients with severe carotid artery stenosis or occlusion, redistribution of blood flow through the cerebral collateral pathways improves cerebral perfusion in ischemic areas and may protect against ischemic events.[4,5] The recruitment of circle of Willis collateral flow to any ischemic area depends on the presence and patency of its component vessels.

Because of prior limitations in non-invasive evaluation methods, current knowledge of the morphologic variations in the circle of Willis is mainly based on postmortem autopsy studies. Recent technical advance in CT angiography (CTA) technology have made direct visualization of the circle of Willis collaterals possible in large patient populations.[6]

The morphological characteristics of the circle of Willis have been documented in various studies of patients with cerebrovascular disorders.[7,8] In previous reports, the absence of cerebral collateral function has been regarded as a risk factor for ischemic stroke.[9] Recently, correlations between certain types of variations in the circle of Willis and development of intracranial aneurysms have been proposed.[10,11] In previous studies, it has been noted that considerable cerebral collateral variations exist in patients with cerebrovascular disorders. However, previous studies have only documented the variations of the collateral circulation in Western populations, and the configuration of the collateral circulation in a Chinese population remains largely unknown. We hypothesized that the collateral circulation may differ in different ethic groups. Thus, the purpose of our study was to investigate the morphologic variations in the circle of Willis in a Chinese population using 64-section CTA and to compare our findings with previous reports from Western countries.

2. Materials and methods

2.1. Participants

This study was approved by the Ethics Committee of Chongqing Medical University. Informed consent was obtained from all participants. A total of 170 healthy participants (86 men, 84 women; mean age, 46 years) who underwent 64-section CTA at The First Affiliated Hospital of Chongqing Medical University were retrospectively reviewed for evaluation of the circle of Willis configurations. Inclusion criteria were as follows: (i) no past history of transient ischemic attack, acute ischemic stroke or hemorrhagic stroke; (ii) no disabling neurological deficits on examination; and

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(iii) the CT angiograms were diagnostic for delineation of the circle of Willis. Subjects were excluded from our study if they had brain abnormalities detected on unenhanced CT scan or CT angiograms.

2.2. Imaging studies

All participants underwent three-dimensional (3D) cranial CTA with a 64-section multidetector CT scanner (Lightspeed VCT; GE Medical Systems, Milwaukee, WI, USA). Before CTA examination, patients' heads were comfortably fixed by a head holder to prevent motion artifacts. Participants were placed supine and the scan volume extended from the first cervical vertebra to the cranial vault. A total of 80 mL of non-ionic contrast medium (iopromide, 370 mg iodine/mL) was injected through an 18-gauge needle via the antecubital vein with an automated injector at a flow rate of 4 mL/s. The scanning delay was automatically adjusted for each individual by a bolus tracking technique. A contrast-enhanced image was obtained with the following parameters: 120 kV, 300 mA, pitch of 0.531, section thickness of 0.5 mm, 0.5 mm increment, 180 mm field-of-view, 512 × 512 matrix with soft reconstruction kernel. Image postprocessing was performed at a workstation (Advantage for Windows, GE Medical Systems). After successful acquisition of CTA datasets, the source images were reformatted as 3D volume rendering (VR) and maximum intensity projection (MIP) angiograms.

2.3. Image analysis

The CTA images were sent to a workstation for further evaluation. The circle of Willis configuration was assessed based on source images as well as 3D VR and MIP angiograms. Two observers, who were blinded to each other's assessments, independently reviewed the CT angiograms at the circle of Willis. If they had disagreements regarding the configuration of the circle of Willis, they discussed it until a consensus was reached. All component vessels at the circle of Willis were assessed in each individual. In interpretation of the CT angiograms, the observers assessed the presence or absence of each arterial segment in the circle of Willis. If an arterial segment was visible, the diameters of bilateral A1, P1 and posterior communicating arteries (PcomA) were measured. Arterial segments that were larger than 1 mm were considered to be normal. Arterial segments that were less than 1 mm were classified as hypoplastic. The anterior part of the circle was classified according to the schematic diagram in Fig. 1. In evaluation of the posterior part of the circle of Willis, the P1 segment was assessed in relation to the ipsilateral PcomA. The posterior collaterals were classified as one of three variants: an adult configuration, a transitional configuration and a fetal configuration. The schematic diagram of posterior variants is shown in Fig. 2. Vessels arising from the internal carotid artery that had diameters larger than P1 and continued as posterior cerebral arteries were regarded as a fetal-type posterior cerebral artery. The transitional configuration was defined as a variant in which the diameters of the PcomA and the P1 segment were the same. In the adult configuration, the PcomA was smaller than the ipsilateral P1. Examples of the morphological variations in the circle of Willis are shown in Fig. 3.

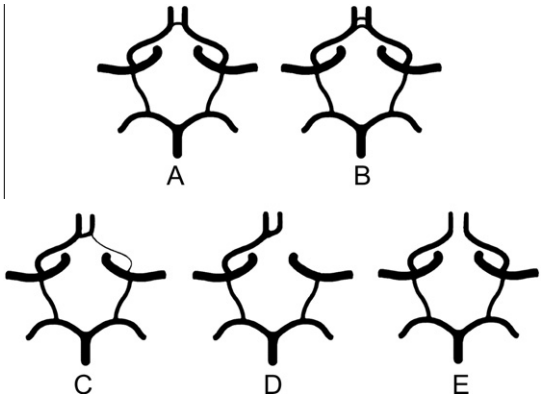

Fig. 1. Schematic diagram of anatomical variations in the anterior part of the circle of Willis showing: (A) normal anterior circle; (B) two anterior communicating arteries; (C) A1 hypoplasia; (D) A1 aplasia; and (E) absence of the anterior communicating artery.

2.4. Statistical analysis

The Fisher exact test was applied to calculate the significance of the sex-related differences in the anatomic variations of the anterior and posterior circle. A p value of <0.05 was considered statistically significant.

3. Results

3.1. Participants

All participants underwent a 64-section CTA examination at our institution. There were no technical failures or complications. Of the 170 participants who underwent CTA examination, seven were excluded because of incidental aneurysms ($n = 5$), an arteriovenous malformation ($n = 1$) and moyamoya disease ($n = 1$) on CT angiograms. Thus, the circle of Willis configurations were evaluated in 163 participants. However, another three participants were excluded from the final analysis because assessment of some arterial segments at the circle of Willis was obscured by motion artifacts. Consequently, 160 participants (82 men, 78 women; mean age, 46 years) were included in the final analysis.

3.2. Anterior circle of Willis variants

The morphological variations of the anterior circle of Willis are listed in Table 1. In total, the anterior circle of Willis was complete in 126 of 160 participants (79%), of whom a normal configuration was seen in 122 subjects. In four patients, two anterior communicating arteries were observed. The anterior circle was incomplete in 34 participants who had compromised anterior collateral flow, of whom the anterior communicating artery was invisible (absent) in 15 (Fig. 1E). The remaining 19 subjects had A1 hypoplasia (Fig. 1C) or aplasia (Fig. 1D). The most common type of anterior collateral was type A (normal), in which all component vessels were competent. There were no statistically significant sex-related differences in the anterior part of the circle.

3.3. Posterior circle of Willis variants

The prevalence of the posterior circle of Willis variants are listed in Table 2. No statistically significant sex-related differences were found in the posterior circle of Willis. A significantly higher percentage of incomplete collaterals were observed in the posterior part of the circle compared with the anterior collaterals ($p < 0.05$). The most common type of posterior variation was type E (Fig. 2E), in which bilateral PcomA were absent. Of the 50 participants with complete posterior circles, an adult configuration (Fig. 2A) was observed in 28 participants, and a very rare transitional variant (Fig. 2B) was observed in seven participants. A fetal-type posterior circle of Willis (FTP, Fig. 2C, Fig. 2D and Fig. 2IG) was seen in 17 (11%) of the 160 subjects. Of the 17 subjects with FTP, 15 (94%) were classified as having partial FTP